APPARATUS AND METHOD FOR ESTIMATING CHARGE RATE OF SECONDARY CELL

BACKGROUND OF THE INVENTION:

Field of the invention

[0001] The present invention relates to apparatus and method for estimating a charge rate (abbreviated as SOC) of a secondary cell.

Description of the related art

[0002] Japanese Patent Application First Publications No. 2000-323183 published on November 24, 2000 No. 2000-268886 published on September 29, 2000, and a Japanese Paper titled " Estimation of Open Voltage and Residual Values for Pb Battery by Adaptive Digital Filter " announced by a Japanese Electrical Engineering Society (T.IEEE Japan), Volume 112-C, No. 4, published on 1992 exemplify previously proposed SOC estimating apparatus for the secondary cell. That is to say, since the charge rate (or called State Of Charge, i.e., SOC) of the secondary cell has a correlation to an open-circuit voltage Vo (cell terminal voltage when its power supply of the cell is turned off, also called electromotive force or open voltage), the charge rate can be estimated when open voltage Vo is obtained. However, a considerable time is needed until the terminal voltage is stabilized after the power supply is turned off (charge-and-discharge is ended). Hence, a predetermined time duration is needed from a time at which the charge-and-discharge is ended to determine an accurate open-circuit voltage Vo. Therefore, since immediately after or during the charge/discharge time or charge-and-discharge, it is impossible to

determine an accurate open-circuit voltage and the charge rate cannot be obtained using the above-described method. Nevertheless, to determine the open-circuit voltage Vo, the open-circuit voltage Vo is estimated using a method disclosed in the above-described Japanese Patent Application First Publication No. 2000-323183.

SUMMARY OF THE INVENTION:

[0003] However, in the above-described method disclosed in the Japanese Patent Application Publication No. 2000-323183, open-circuit voltage Vo is calculated from a non-recursive (non-regression type) cell model (a model whose output value is determined only from a present value and past value of an input value) whose characteristic is wholly different from a physical characteristic of the cell for which an adaptive digital filter (sequential type model parameter identification algorithm) is used. The charge rate SOC is used from this value. Hence, in a case where this method is applied to the actual cell characteristic (input: current, output: voltage), according to the cell characteristic, an estimation calculation is wholly converged or does not converge to a real value. Hence, it is difficult to estimate the charge rate SOC accurately.

[0004] It is, hence, an object of the present invention to provide apparatus and method for estimating accurately the charge rate (SOC) for the secondary cell and accurately estimating other parameters related to the charge rate (SOC).

[0005] According to one aspect of the present invention, there is provided a charge rate estimating apparatus for a secondary cell, comprising: a current

detecting section capable of measuring a current flowing through the secondary cell; a terminal voltage detecting section capable of measuring a voltage across terminals of the secondary cell; a parameter estimating section that calculates an adaptive digital filtering using a cell model in a continuous time series shown in an equation (1) and estimates all of parameters at one time, the parameters corresponding to an open-circuit voltage which is an offset term of the equation (1) and coefficients of A(s), B(s), and C(s) which are transient terms; and a charge rate estimating section that estimates the charge rate from a relationship between a previously derived open-circuit voltage V_0 and the charge rate SOC using the open-circuit voltage V_0,

$$V = \frac{B(s)}{A(s)} \bullet I + \frac{1}{C(s)} \bullet V_0$$ --- (1), wherein s denotes a Laplace transform operator, A(s), B(s), and C(s) denote poly-nominal functions of s.

[0006] According to another aspect of the present invention, there is provided a charge rate estimating method for a secondary cell, comprising: measuring a current flowing through the secondary cell; measuring a voltage across terminals of the secondary cell; calculating an adaptive digital filtering using a cell model in a continuous time series shown in an equation (1); estimating all of parameters at one time, the parameters corresponding to an open-circuit voltage which is an offset term of the equation (1) and coefficients of A(s), B(s), and C(s) which are transient terms; and estimating the

charge rate from a relationship between a previously derived open-circuit voltage V_0 and the charge rate SOC using the open-circuit voltage V_0,

$$V = \frac{B(s)}{A(s)} \bullet I + \frac{1}{C(s)} \bullet V_0 \quad \text{--- (1)},$$ wherein s denotes a Laplace transform operator, A(s), B(s), and C(s) denote poly-nominal functions of s.

[0007] According to a still another object of the present invention, there is provided a charge rate estimating method for a secondary cell, comprising: measuring a current I(k) flowing through the secondary cell; measuring a terminal voltage V(k) across the secondary cell; storing the terminal voltage V(k) when a current is zeroed as an initial value of the terminal voltage ΔV(k) = V(k) - V_ini; determining instantaneous current values $I_0(k)$, $I_1(k)$, and $I_3(k)$ and instantaneous terminal voltages $V_1(k)$, $V_2(k)$, and $V_3(k)$ from an equation (19),

$$I_0 = \frac{1}{G_1(s)} \bullet I,$$

$$I_1 = \frac{s}{G_1(s)} \bullet I, \qquad V_1 = \frac{s}{G_1(s)} \bullet V,$$

$$I_2 = \frac{s^2}{G_1(s)} \bullet I, \qquad V_2 = \frac{s^2}{G_1(s)} \bullet V,$$

$$I_3 = \frac{s^3}{G_1(s)} \bullet I, \qquad V_3 = \frac{s^3}{G_1(s)} \bullet V, \quad \text{and}$$

$$\frac{1}{G_1(s)} = \frac{1}{(p1 \bullet s + 1)^3} \quad \text{---- (19)},$$ wherein p1 denotes a constant determining a responsive characteristic of $G_1(s)$; substituting the instantaneous current values $I_0(k)$, $I_1(k)$, and $I_3(k)$ and the instantaneous terminal voltages $V_1(k)$, $V_2(k)$, and $V_3(k)$ into an equation (18),

$$\gamma(k) = \frac{\lambda_3(k)}{1+\lambda_3(k)\bullet\omega^T(k)\bullet P(k-1)\bullet\omega(k)}$$

$$\theta(k) = \theta(k-1) - \gamma(k)\bullet P(k-1)\bullet\omega(k)\bullet[\omega^T(k)\bullet\theta(k-1) - y(k)]$$

$$P(k) = \frac{1}{\lambda_1(k)}\left\{P(k-1) - \frac{\lambda_3(k)\bullet P(k-1)\bullet\omega(k)\bullet\omega^T(k)\bullet P(k-1)}{1+\lambda_3(k)\bullet\omega^T(k)\bullet P(k-1)\bullet\omega(k)}\right\} = \frac{P'(k)}{\lambda_1(k)}$$

$$\lambda_1(k) = \begin{cases} \dfrac{trace\{P'(k)\}}{\gamma_U} : \lambda_1 \le \dfrac{trace\{P'(k)\}}{\gamma_U} \\ \lambda_1 : \dfrac{trace\{P'(k)\}}{\gamma_U} \le \lambda_1 \le \dfrac{trace\{P'(k)\}}{\gamma_L} \\ \dfrac{trace\{P'(k)\}}{\gamma_L} : \dfrac{trace\{P'(k)\}}{\gamma_L} \le \lambda_1 \end{cases}$$

---- (18), wherein $\theta(k)$ denotes a parameter estimated value at a time point of k (k = 0, 1, 2, 3 ---), λ_1, $\lambda_3(k)$, γu, and γL denote initial set value, $b < \lambda_1 < 1$, $0 < \lambda_3(k) < \infty$. P(0) is a sufficiently large value, $\theta(0)$ provides an initial value which is non-zero but very sufficiently small value, trace{P} means a trace of matrix P, wherein $y(k) = V_1(k)$

$$\omega^T(k) = [V_3(k) \quad V_2(k) \quad I_3(k) \quad I_2(k) \quad I_1(k) \quad I_0(k)]$$

$$\theta(k) = \begin{bmatrix} -a(k) \\ -b(k) \\ c(k) \\ d(k) \\ e(k) \\ f(k) \end{bmatrix} \qquad \text{---- (20);}$$

substituting a, b, c, d, e, and f in the parameter estimated value $\theta(k)$ into and equation (22) to calculate V_0' which is an alternate of V_0 which corresponds to a variation $\Delta V_0(k)$ of the open-circuit voltage estimated value from a time at which the estimated calculation start is carried out;

$V_0' = \frac{(T_1 \bullet s + 1)}{G_2(s)} \bullet V_0 = a \bullet V_6 + b \bullet V_5 + V_4 - c \bullet I_6 - d \bullet I_5 - e \bullet I_4$ --- (22); and calculating an open-circuit voltage estimated value $V_0(k)$ according the variation $\Delta V_0(k)$ of the open-circuit voltage estimated value and the terminal voltage initial value V_ini.

[0008] This summary of the invention does not necessarily describe all necessary features so that the invention may also be a sub-combination of these described features.

BRIEF DESCRIPTION OF THE DRAWINGS:

[0009] Fig. 1 is a functional block diagram of an apparatus for estimating a charge rate (SOC) of a secondary cell in a preferred embodiment according to the present invention.

[0010] Fig. 2 is a specific circuit block diagram of the apparatus for estimating the charge rate of the secondary cell in the preferred embodiment according to the present invention.

[0011] Fig. 3 is a model view representing an equivalent circuit model of the secondary cell.

[0012] Fig. 4 is a correlation map representing a correlation between an open-circuit voltage and a charge rate (SOC).

[0013] Fig. 5 is an operational flowchart for explaining an operation of a microcomputer of a battery controller of the charge rate estimating apparatus in the first preferred embodiment shown in Fig. 1.

[0014] Figs. 6A, 6B, 6C, 6D, 6E, 6F, 6G, 6H and 6I are characteristic graphs representing results of simulations of current, voltages, and various

parameters in a case of the charge rate estimating apparatus in the embodiment shown in Fig. 1

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT:

[0015] Reference will hereinafter be made to the drawings in order to facilitate a better understanding of the present invention.

[0016] Fig. 1 shows a functional block diagram of charge rate estimating apparatus in a first preferred embodiment according to the present invention. In Fig. 1, a reference numeral 1 denotes a parameter estimating section based on a cell model with an open-circuit voltage Vo(k) as an offset term. In addition, a reference numeral 2 denotes a open-circuit voltage calculating section to calculate open-circuit voltage Vo(k), and a reference numeral 3 denotes a charge rate estimating section that calculate the charge rate from the open-circuit voltage. In addition, a reference numeral 4 denotes a current I measuring block to detect current I(k) which is charged and discharged into and from the cell, and a reference numeral 5 denotes s terminal voltage of the cell to measure the terminal voltage V(k).

[0017] Fig. 2 shows a block diagram representing a specific structure of the charge rate estimating apparatus in the first embodiment. In this embodiment, a load such as a motor is driven with the secondary cell and the charge rate estimating apparatus is mounted in a system to charge the secondary cell with a regenerative power of the motor (load). In Fig. 2, a reference numeral 10 denotes a secondary cell (simply called, a cell), a reference numeral 20 denotes a load such as a DC motor, a reference

numeral 30 denotes a battery controller (electronic control unit) to estimate the charge rate (charge state) of the cell having a microcomputer including a ROM (Read Only Memory), a RAM (Random Access Memory), a CPU (central Processing Unit), and Input/Output Interface and other electronic circuits. A reference numeral 40 denotes a current meter to detect a current which is charged into or discharged from the cell, a reference numeral 50 denotes a voltage meter to detect the terminal voltage of the cell, a reference numeral 60 denotes a temperature meter to detect a temperature of the cell. These meters are connected to battery controller 30. Battery controller 30 corresponds to parts of parameter estimating section 1, an open-circuit voltage Vo(k) and a charge rate estimating section 3. Current meter 40 corresponds to current I(k) measuring section and voltage meter 50 correspond to terminal voltage V(k) measuring section 5.

[0018] First, a " cell model " used in the first embodiment will be described below. Fig. 3 is an equivalent circuit representing an equivalent circuit model of the secondary cell. The equivalent circuit model of the secondary cell can be represented by the following equation (7) (= equation (6)).

$$V = \frac{K \bullet (T_2 \bullet s + 1)}{T_1 \bullet s + 1} \bullet I + \frac{1}{T_3 \bullet s + 1} V_0 \quad --- \ (7).$$

In equation (7), a model input is a current I [A] (a positive value represents a charge and a negative value represents a discharge), a model output is a terminal voltage V [V], an open-circuit voltage is V_0, K denotes an internal resistance, T_1

through T_3 denote time constants ($T_1 \neq T_2 \neq T_3$, $T_1 \ll T_3$) and s denotes a Laplace transform operator.

[0019] In this model based on equation of (7) is a reduction model (first order) in which a positive pole and a negative pole are not specially separated from each other. However, it is possible to represent a charge-discharge characteristic of an actual cell relatively easily. Equation (7), in equation (1) of $V = B(s)/A(s) \cdot I + 1/C(s) \cdot V_0$ --- (1), $A(s) = T_1 \cdot s + 1$, $B(s) = K \cdot (T_2) \cdot s + 1$, $C(s) = T_3 \cdot s + 1$.

[0020] Hereinafter, a deviation from the cell model based on equation (7) to an adaptive digital filter will first be described below. Open-circuit voltage V_0 can be described by an equation (8), supposing that a value of a current I multiplied with a variable efficiency of A is integrated from a certain initial state.

That is to say, $V_0 = \frac{A}{s} \cdot I$ --- (8).

It is noted that equation (8) corresponds to a replacement of h recited in equation (2), viz., $V_0 = h/s \cdot I$ with efficiency of A.

[0021] If equation (8) is substituted into equation (7), equation (9) is resulted.

$$V_0 = \frac{K \cdot (T_2 \cdot s + 1)}{T_1 \cdot s + 1} \cdot I + \frac{1}{T_3 \cdot s + 1} \cdot \frac{A}{s} \cdot I \quad \text{--- (9).}$$

Equation (9) corresponds to equation (3) ($V = \left(\frac{B(s)}{A(s)} + \frac{1}{C(s)} \cdot \frac{h}{s}\right) \cdot I = \frac{s \cdot B(s) \cdot C(s) + h \cdot A(s)}{s \cdot A(s) \cdot C(s)} \cdot I$ --- (3)). For A(s), B(s), and C(s) in equation (3), the following equations are substituted into equation (9) in the same way as the case of equation (7).

$A(s) = T_1 \cdot s + 1,$

$B(s) = K \cdot (T_2 \cdot s + 1)$

$C(s) = T_3 \cdot s + 1.$ In other words, equation (3) is a generalized equation and this application to a first order model is equation (9). If equation (9) is arranged, an equation of (10) is given.

$S \cdot (T_1 \cdot s + 1)(T_3 \cdot s+1) \cdot V = K \cdot (T_2 \cdot s + 1)(T_3 \cdot s + 1)s \cdot I + A \cdot (T_1 \cdot s + 1) \cdot I$

$\{T_1 \cdot T_3 \cdot s^3 + (T_1 + T_3) \cdot s^2 + s\} \cdot V = \{K \cdot T_2 \cdot T_3 \cdot s^3 + K \cdot (T_2 + T_3) \cdot s^2 + (K + A \cdot T_1) \cdot s + A\} \cdot I$

$(a \cdot s^3 + b \cdot s^2 + s) \cdot V = (c \cdot s^3 + d \cdot s^2 + e \cdot s + f) \cdot I$ --- (10). It is noted that, in the last equation of equation (10), parameters are rewritten as follows: $a = T_1 \cdot T_3$, $b = T_1 + T_3$, $c = K \cdot T_2 \cdot T_3$, $d = K \cdot (T_1 + T_3)$, $e = K + A \cdot T_1$, and $f = A$ --- (11).

If a stable low pass filter $G_1(s)$ is introduced into both sides of equation (10) and arranged, the following equation (12) is given.

$\frac{1}{G_1(s)}(a \cdot s^3 + b \cdot s^2 + s) \cdot V = \frac{1}{G_1(s)}(c \cdot s^3 + d \cdot s^2 + e \cdot s + f) \cdot I$ --- (12). In details, in equation (10), on the contrary of equation (7), if $T_1 \cdot s + 1 = A(s)$, $K \cdot (T_2 \cdot s + 1) = B(s)$, and $T_3 \cdot s + 1 = C(s)$ are substituted into equation (10), this is given as: $s \cdot A(s) \cdot C(s) \cdot V = B(s) \cdot C(s) \cdot s \cdot I + A \cdot A(s) \cdot I$. This is rearranged as follows: $s \cdot A(s) \cdot C(s) \cdot V = [B(s) \cdot C(s) \cdot s \cdot I + A \cdot A(s)] \cdot I$ --- (12)'. If, the low pass filter (LPF), $G_1(s)$ is introduced into both sides of equation (12)', an equation (4) is given.

That is to say, $\frac{s \bullet A(s) \bullet C(s)}{G_1(s)} \bullet V = \frac{s \bullet B(s) \bullet C(s) + h \bullet A(s)}{s \bullet A(s) \bullet C(s)} \bullet I$ --- (4). It is noted that s denotes the Laplace transform operator, A(s), B(s), and C(s) denote a poly-nominal function of s, h denotes a variable, and $1/G_1(s)$ denotes a transfer function having a low pass filter characteristic. That is to say, equation (4) is the generalized function, equation (12) is the application of equation (4) to the first order model.

[0022] Current I and terminal voltage V which can actually be measured are processed by means of a low pass filter (LPF) and a band pass filter (BPF) are defined in the following equations (13), provided that p_1 denotes a constant to determine a responsive characteristic of G1(s) and is determined according to a designer's desire.

$$I_0 = \frac{1}{G_1(s)} \bullet I$$

$$I_1 = \frac{s}{G_1(s)} \bullet I, \qquad V_1 = \frac{s}{G_1(s)} \bullet V,$$

$$I_2 = \frac{s^2}{G_1(s)} \bullet I, \qquad V_2 = \frac{s^2}{G_1(s)} \bullet V,$$

$$I_3 = \frac{s^3}{G_1(s)} \bullet I, \qquad V_3 = \frac{s^3}{G_1(s)} \bullet V,$$

$$\frac{1}{G_1(s)} = \frac{1}{(P_1 \bullet s + 1)^3} \qquad \text{--- (13)}$$

If equation (12) is rewritten using the variables shown in equations (13), equations (14) are represented and, if deformed, the following equation (15) is given.

$$a \bullet V_3 + b \bullet V_2 + V_1 = c \bullet I_3 + d \bullet I_2 + e \bullet I_1 + f \bullet I_0$$

$$V_1 = -a \bullet V_3 - b \bullet V_2 + c \bullet I_3 + d \bullet I_2 + e \bullet I_1 + f \bullet I_0 \quad \text{---} \ (14).$$

$$V_1 = [V_3 \quad V_2 \quad I_3 \quad I_2 \quad I_1 \quad I_0] = \begin{bmatrix} -a \\ -b \\ c \\ d \\ e \\ f \end{bmatrix} \quad \text{---} \ (15).$$

Equation (15) is a product-sum equation of measurable values and unknown parameters. Hence, a standard (general) type (equation (16)) of the adaptive digital filter is coincident with equation (15). It is noted that ω^T means a transposed vector in which a row and column of a vector ω are mutually exchanged.

$$y = \omega^T \bullet \theta \quad \text{---} \ (16).$$ It is noted that y, ω^T, and θ can be expressed in the following equation (17) in equation (16) described above.

$$Y = V_1, \ \omega^T = [V_3 \quad V_2 \quad I_3 \quad I_2 \quad I_1 \quad I_0], \ \theta = \begin{bmatrix} -a \\ -b \\ c \\ d \\ e \\ f \end{bmatrix} \quad \text{---} \ (17).$$

Hence, if a signal filter processed for current I and terminal voltage V is used in a digital filter process calculation, unknown parameter vector θ can be estimated.

[0023] In this embodiment, " a both-limitation trace gain method is used which improves a logical demerit of a simple " an adaptive digital filter by means of a least square method " such that once the

estimated value is converged, an accurate estimation cannot be made any more even if the parameters are changed. A parameter estimating algorithm to estimate unknown parameter vector θ with equation (16) as a prerequisite is as shown in an equation (18). It is noted that the parameter estimated value at a time point of k is $\theta(k)$.

$$\gamma(k) = \frac{\lambda_3(k)}{1+\lambda_3(k)\bullet\omega^T(k)\bullet P(k-1)\bullet\omega(k)}$$

$$\theta(k) = \theta(k-1) - \gamma(k)\bullet P(k-1)\bullet\omega(k)\bullet[\omega^T(k)\bullet\theta(k-1) - y(k)]$$

$$P(k) = \frac{1}{\lambda_1(k)}\left\{P(k-1) - \frac{\lambda_3(k)\bullet P(k-1)\bullet\omega(k)\bullet\omega^T(k)\bullet P(k-1)}{1+\lambda_3(k)\bullet\omega^T(k)\bullet P(k-1)\bullet\omega(k)}\right\} = \frac{P'(k)}{\lambda_1(k)}$$

$$\lambda_1(k) = \begin{cases} \dfrac{trace\{P'(k)\}}{\gamma_U} : \lambda_1 \le \dfrac{trace\{P'(k)\}}{\gamma_U} \\ \lambda_1 : \dfrac{trace\{P'(k)\}}{\gamma_U} \le \lambda_1 \le \dfrac{trace\{P'(k)\}}{\gamma_L} \\ \dfrac{trace\{P'(k)\}}{\gamma_L} : \dfrac{trace\{P'(k)\}}{\gamma_L} \le \lambda_1 \end{cases}$$

---------------------------------- (18).

In equations (18), λ_1, $\lambda_3(k)$, γ_u, and γ_L denote initial set value, $b < \lambda_1 < 1$, $0 < \lambda_3(k) < \infty$. P(0) is a sufficiently large value, $\theta(0)$ provides an initial value which is non-zero but very sufficiently small value. In addition, trace{P} means a trace of matrix P. As described above, the derivation of the adaptive digital filter from cell model.

[0024] Fig. 5 shows an operational flowchart carrying out the microcomputer of battery controller 30. A routine shown in 5 is carried out for each constant period of time T_0. For example, I(k) is the present value and I(k -1) means a one previous value

of I(k). At a step S10, battery controller 30 measures current I(k) and I(k -1) means one previous value of I(k). At s step S20, battery controller 30 carries out a turn on-and-off determination of an interrupt relay of the secondary cell. That is to say, battery controller 30 performs the on-and-off control of the interrupt relay of the secondary cell. When a relay is turned off (current I = 0), the routine goes to a step S30. During the engagement of the relay, the routine goes to a step S40. At step S30, when the relay is engaged, the routine goes to a step S540. At step S530, battery controller 30 serves to store terminal voltage V(k) to as an initial value of the terminal voltage V_ini. At a step S40, battery controller 30 calculates a differential value $\Delta V(k)$ of the terminal voltage. $\Delta V(k) = V(k) - V\_ini$. This is because the initial value of the estimation parameter in the adaptive digital filter is 0 so that the estimation parameter does not converge during the estimation calculation start time. Thus, all of inputs are zeroed. During the input being all zeroed. During the relay interruption, step S30 have been passed and the estimation parameters are remains initial state since I = 0 and the estimation parameter remains alive.

[0025] At step S50, a low pass filtering or band pass filtering are carried out the current I(k) and terminal voltage difference value $\Delta V(k)$ on the basis of equation (13). $I_0(k)$ through $I_3(k)$ and $V_1(k)$ through $V_3(k)$ are calculated from equation (19). In this case, in order to improve an estimation accuracy of the parameter estimation algorithm of equation (18), a responsive characteristic of low pass filter

$G_1(s)$ is set to be slow so as to reduce observation noises. However, if the characteristic is quicker than a response characteristic of the secondary cell (a rough value of time constant T_1 is known), each parameter of the electric cell model cannot accurately be estimated. It is noted that p_1 recited in equation (19) denotes a constant determined according to the responsive characteristic of $G_1(s)$.

[0026] $I_0 = \dfrac{1}{G_1(s)} \bullet I$,

$$I_1 = \frac{s}{G_1(s)} \bullet I, \qquad V_1 = \frac{s}{G_1(s)} \bullet V,$$

$$I_2 = \frac{s^2}{G_1(s)} \bullet I, \qquad V_2 = \frac{s^2}{G_1(s)} \bullet V,$$

$$I_3 = \frac{s^3}{G_1(s)} \bullet I, \qquad V_3 = \frac{s^3}{G_1(s)} \bullet V, \text{ and}$$

$$\frac{1}{G_1(s)} = \frac{1}{(p1 \bullet s + 1)^3}$$

------------ (19).

At a step S60, $I_0(k)$ through $I_3(k)$ calculated at step S50 and $V_1(k)$ through $V_3(k)$ are substituted into equation (18). Then, the parameter estimation algorithm in the adaptive digital filter, viz., equation (18) is executed to calculate parameter estimated value $\theta(k)$. $y(k)$, $\omega^T(k)$, and $\theta(k)$ are shown in equation (20).

$$y(k) = V_1(k)$$

$$\omega^T(k) = [V_3(k) \quad V_2(k) \quad I_3(k) \quad I_2(k) \quad I_1(k) \quad I_0(k)]$$

$$\theta(k) = \begin{bmatrix} -a(k) \\ -b(k) \\ c(k) \\ d(k) \\ e(k) \\ f(k) \end{bmatrix} \quad ---- (20).$$

At a step S70, a through e of parameter estimated value θ(k) calculated at step S60 are substituted into the following equation (22) in which the above-described cell model equation (7) is deformed to calculate V_0' which is an alternative to open-circuit voltage V_0. Since the variation in open-circuit voltage V_0 is smooth, V_0' can be used alternatively. It is noted that the derivation herein is a variation $\Delta V_0(k)$ of the open-circuit voltage from the estimated calculation start time.

[0027] It is noted that an equation of [1/C1(s)]I in equation (21) is replaced with an equation (24) corresponds to equation (22). It is also noted that, in the derivation of equation (22), K in equation (21) is strictly different from e in equation (21). However, since, physically, $K \gg A \bullet T_1$, e is approximated to K ($e \cong K$). Then, each coefficient a through e in equation (22) is the contents shown in equation (23).

$$\frac{1}{T_3 \bullet s+1} \bullet V_0 = V - \frac{K \bullet (T_2 + s + 1)}{T_1 \bullet s + 1} \bullet I$$

$$(T_1 \bullet s + 1) \bullet Vo = (T_1 \bullet s + 1)(T_3 \bullet s + 1)V - K \bullet (T_2 \bullet s + 1)(T_3 \bullet s + 1) \bullet I$$

$$(T_1 \bullet s + 1) \bullet V_0 = \{T_1 \bullet T_3 \bullet s^2 + (T_1 + T_3) \bullet s + 1\} \bullet V - \{K \bullet T_2 \bullet T_3 \bullet s^2 + K \bullet (T_2 + T_3) \bullet s + K\} \bullet I$$

$$\frac{(T_1 \bullet s+1)}{G_2} \bullet V_0 = \frac{1}{G_2(s)}(a \bullet s^2 + b \bullet s + K) \bullet I$$

--- (21).

V'_0 = $\frac{(T_1 \bullet s+1)}{G_2(s)} \bullet V_0$ = $a \bullet V_6$ + $b \bullet V_5$ + V_4 - $c \bullet I_6$ - $d \bullet I_5$ - $e \bullet$ I_4 --- (22).

[0028] It is noted that $a = T_1 \bullet T_3$, $b = T_1 + T_3$, $c = K \bullet (T_2 + T_3\}$, $d = K \bullet (T_2 + T_3)$, $e = K + A \bullet T_1 = K$ --- (23).

[0029] $I_4 = \frac{1}{G_2(s)} \bullet I$, $V_4 = \frac{1}{G_2(s)} \bullet V$,

$I_5 = \frac{s}{G_2(s)} \bullet I$, $V_5 = \frac{s}{G_2(s)} \bullet V$,

$$\frac{1}{G_2(s)} = \frac{1}{p_2 \bullet s+1} \bullet \frac{1}{T_1' \bullet s+1},$$

$I_6 = \frac{s^2}{G_2(s)} \bullet I$, and $V_6 = \frac{s^2}{G_2(s)} \bullet V$ ---- (24).

[0030] p_2 recited in equations (24) denote a constant to determine a responsive characteristic of $G_2(s)$. T_1 of the cell parameter is known to be several seconds. Hence, T'_1 in equation (24) is set to be approximated value to T_1. Thereby, since ($T_1 \bullet$ s + 1) which remains in a numerator of equation (22) can be compensated, the estimation accuracy of open-circuit voltage V_0 can be improved. It is noted that equation (21) corresponds to equation (5). That is to say, equation (21) is derived from $(T_1 \bullet s +1) \bullet V_0 = (T_1 \bullet s + 1)(T_3 \bullet s + 1) \bullet V - K \bullet (T_2 \bullet s + 1)(T_3 \bullet s +1) \bullet (T_3 \bullet s + 1) \bullet I$. If the following three equations are substituted into the above-described deformation of equation (21). $T_1 \bullet s + 1 = A(s)$, $K \bullet (T_2 \bullet s + 1)$

$B(s)$, and $T_3 \cdot s + 1 = C(s)$. That is to say, $A(s) \cdot V_0 = A(s) \cdot C(s) \cdot V - B(s) \cdot C(s) \cdot I$. If this is rearranged, this results in $V_0 = C(s) \cdot V - B(s) \cdot C(s) \cdot I/A(s)$, $V_0 = C(s) \cdot [V - B(s) \cdot I/A(s)]$ If low pass filter $G_2(s)$ is introduced into both sides of this equation, this results in equation (5). In details, equation (5) is a generalization equation and the application of equation (5) to the first order model is equation (2).

[0031] At a step S80, battery controller 30 adds the open-circuit voltage initial value, i.e., terminal voltage initial value V_ini to a variation $\Delta V_0(k)$ of open-circuit voltage V_0 so as to obtain open-circuit voltage estimated value $V_0(k)$ from the following equation (25).

$$V_0(k) = \Delta V_0(k) + V\_ini \quad --- (25).$$

[0032] At a step S90, battery controller 30 calculates the charge rate SOC(k) from open-circuit voltage $V_0(k)$ calculated at step S80 using a correlation map of the open-circuit voltage versus the charge rate as shown in Fig. 4. It is noted that, in Fig. 4, V_L denotes the open-circuit voltage corresponding to SOC = 0 % and V_H denotes the open-circuit voltage corresponding to SOC = 100 %. At a step S100, battery controller 30 stores the necessary numerical values needed in the subsequent calculation and the present routine is ended. As described above, an operation of the apparatus for estimating the charge rate of the secondary cell has been described.

[0033] (1) As described above, a relationship from among current I of the secondary cell and terminal voltage V thereof, and the open-circuit voltage V0 is structured in transfer function that as

in the general equation (1), that in the preferred embodiment, equation (7) (= equation (6). Hence, it is made possible to apply an adaptive digital filter such as a least square method (well known estimation algorithm). Consequently, it becomes possible to estimate parameters in equations (viz., open-circuit voltage V0 which is an offset term and poly-nominal equations A(s), B(s), and C(s)) in a form of a batch processing. These parameters are largely affected by the charge rate, a surrounding temperature, and a deterioration and varied instantaneously. It is possible to sequentially estimate the adaptive digital filter with good accuracy. Then, if a unique correlation between the open-circuit voltage Vo and the charge rate as shown in Fig. 4 are stored, the estimated open-circuit voltage can be converted to the charge rate. Hence, it is possible to sequentially estimate the charge rate in the same way as the parameters described above.

[0034] (2) In a case where the equation (1) which is the relationship equation of current I and terminal voltage V of the secondary cell is approximated to equation (4), the equation such that no offset term is included (viz., the open-circuit voltage V_0), a product-and-addition equation between a measurable current I which is filter processed and a terminal voltage V which is filter processed and unknown parameter (coefficient parameters of poly-nominal equations A(s), B(s), and C(s) and h) is obtained. A normally available adaptive digital filter (the least mean square method and well known parameter estimation algorithm) can directly be applied in a continuous time series.

[0035] As a result of this, the unknown parameters can be estimated in the batch processing manner and the estimated parameter h is substituted into equation (2), the estimated value of open-circuit voltage V_0 can easily be calculated. All of these parameters are varied instantaneously, the adaptive digital filter can serve to estimate the charge rate at any time with a high accuracy. Since a constant relationship between open-circuit voltage Vo and the charge rate SOC is established as shown in Fig. 4, if this relationship is previously stored, the charge rate SOC can be estimated from the estimated value of open-circuit voltage V_0.

[0036] Figs. 6A through 6I integrally shows signal timing charts with current I and terminal voltage V inputted into adaptive digital filter and representing results of simulation graphs when each parameter is estimated. As far as a time constant of a first order delay in equation (6) is concerned, $T_1 < T_0$. Since all parameters a through f (refer to equation (11)) are favorably estimated, the estimated value of open-circuit voltage V_0 can be said to be well coincident with a real value.

[0037] It is noted that, in Fig. 6C which indicates the open-circuit voltage, a reason that a right side second term of equation (6) is described is to indicate that the open-circuit voltage estimated value is coincident with a real value almost without delay in spite of the fact that a late term of time constant T_3 is measured on the terminal voltage inputted into the adaptive filter. In details, since the parameter estimation with the cell model formatted adaptive digital filter in

equation (6), all of parameters a through f can favorably be estimated and the estimated value of open-circuit voltage V_0 is well coincident with a real value.

[0038] (3) In addition, as described in item (2), in the structure in which the open-circuit voltage V_0 is calculated from equation (2), the integration occurs before a value at which estimated value h is converged to the real value, its error cannot be eliminated. However, in the structure in which equation (5) in which the integration is not included, the error before the parameter estimated value is converged into the real value does not give an influence after the convergence.

[0039] It will be appreciated that, in part of ① in Fig. 6I, before estimated value f is converged into a real value, an erroneous estimation is carried out only at momentarily. In equation (2), this value is also integrated so that the error is not eliminated. However, the error is not eliminated since even this value is integrated. However, in the structure using equation (5), open-circuit voltage V0 is calculated from the equation in which the integration is not included. Hence, after the parameter estimated value is converged into the real time, this erroneous estimation portion is eliminated.

[0040] (4) Furthermore, in a case where equation (6) is used in place of equation (1), a calculation time and program capacity can be suppressed to a minimum while having the above-described advantages.

[0040] The entire contents of a Japanese Patent Application No. 2002-340803 (filed in Japan on November 25, 2002) are herein incorporated by

reference. The scope of the invention is defined with reference to the following claims.